Rocky Mountains | Southwest | Great Plains

Research Note RM-462

January 1986

USDA Forest Service
Rocky Mountain Forest and Range Experiment Station

Effect of Prescribed Burning on Soil Moisture and Germination of Southwestern Ponderosa Pine Seed on Basaltic Soils

Sally M. Haase[1]

Prescribed burning created a more favorable seedbed by exposing mineral soil and increasing soil moisture, resulting in a twenty-fold increase in the number of seeds germinating on burned compared to unburned sites.

Keywords: *Pinus ponderosa*, natural regeneration, prescribed burning, site preparation

Management Implications

Successful natural regeneration is dependent on many factors, including a seedbed that is suitable for germination and seedling establishment. The results of this study suggest that prescribed burning may provide such a seedbed for ponderosa pine on basaltic soils. Although overall germination was low, it was significantly higher on burned than unburned sites during a year in which precipitation was below average.

Apparently, prescribed burning reduced the heavy accumulation of litter and duff, allowing seed to reach mineral soil. In contrast, vertical seed movement was minimal on unburned plots, and seeds reached mineral soil only on those plots lying beyond the canopy dripline. Furthermore, germination was probably enhanced by the generally higher moisture content in the upper 2 inches of soil on burned areas.

Successful regeneration of forested areas depends on the establishment of new seedlings in sufficient numbers to adequately restock the stand. Although the study showed that burning improved germination, seedling establishment beyond the first summer was not measured. Also, the low survival rate precluded drawing any conclusions about establishment. Consequently, additional research or pilot demonstrations will be needed before the effectiveness of prescribed burning can be fully evaluated.

[1]*Research Forester, Rocky Mountain Forest and Range Experiment Station. Headquarters is in Fort Collins, in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit at Flagstaff, in cooperation with Northern Arizona University.*

Introduction

Soil type and climate are major factors influencing successful establishment of ponderosa pine in the Southwest (Pearson 1950, Schubert 1974). On areas where limestone is the parent soil material, natural regeneration may become established on mineral soil exposed during logging operations or mechanical site preparation. Natural regeneration on some basaltic soils may be less successful; to compensate, the site may need to be disked and planted (Heidmann et al. 1977).

Schubert (1974) summarized conditions necessary for successful natural regeneration. A large supply of viable seed must be able to reach a well-prepared mineral soil seedbed, free of competing vegetation. The regeneration area must also have sufficient moisture for germination. Prior to germination, the seeds must be protected from seed-eating rodents; afterwards, seedlings must be protected from grazing animals. If any of these factors is not realized, successful regeneration is unlikely. Additionally, frost heaving on basalt-derived soils can kill a large number of seedlings the first winter (Heidmann 1976). Wildfire, as a natural and often-repeated event, has created mineral soil seedbed favorable for regeneration, thinned dense thickets, reduced fire hazard, and provided improved habitat for wildlife (Biswell 1972; Cooper 1961; Fahnestock 1973; Mutch and Habeck 1975; Kallender et al. 1955; Weaver 1951, 1956).

One objective of using prescribed fire in the Southwest is to reduce residues resulting from logging and thinning operations. The average amount of natural ground

fuel—litter, duff, and woody material less than 1-inch in diameter—present in the ponderosa pine forested areas of the Southwest is estimated to be 12.7 tons per acre (Sackett 1979). Generally, litter and duff depths range from 1 to 5 inches under the canopy of mature ponderosa pines.[2] Such litter/duff depths indicate seedbed conditions requiring extensive site preparation measures.

Objectives of this study were (1) to compare seed germination and early seedling establishment of ponderosa pine on burned and unburned sites; (2) to study the effect of prescribed fire on fuel reduction and seedbed preparedness in basaltic soils; and (3) to compare soil moisture on burned and unburned sites in a mature stand of ponderosa pine.

Study Area

Study plots are on the Fort Valley Experimental Forest northwest of Flagstaff, Ariz., at an elevation of approximately 7,200 feet in the *Pinus ponderosa/Festuca arizonica* habitat type. The soil is tentatively classified as Typic Argiborolls, composed of fine montmorillonitic clay-loam,[3] and derived from basalt parent material. The stand is typical of undisturbed southwestern ponderosa pine—uneven aged with small even-aged groups. The last wildfire occurred in 1876 (Dieterich 1980).

Average annual precipitation at Fort Valley Experimental Forest exceeds 22 inches, most coming as snow during the winter months and rain in July and August. Spring and fall are dry periods, with June normally the driest month of the year (Schubert 1974).

Methods

Two treatments (burned and unburned) were replicated six times and randomly assigned to one of 12 study plots, which were centered around one to several mature ponderosa pine. Each plot consisted of eight 1/2-milacre subplots, four on each half of a northeast-southwest transect line extending through the center of the tree or trees (fig. 1). The exact position of each 1/2-milacre subplot varied according to the distance from the base of the tree to the edge of the canopy; on each half of the transect line, three were equally spaced under the canopy while the fourth was beyond it. The 1/2-milacre subplots were permanently marked and divided into two 1/4-milacre subplots; regeneration was measured in the southernmost half and soil moisture in the northernmost.

Plots were burned November 6, 1979, after the study area had received approximately 2 inches of precipitation during the preceding 18 days. The moisture content of the litter before burning was (L) newly cast needles 6.5–8.8%, (F) whole gray needles 8.1–13.1%, and

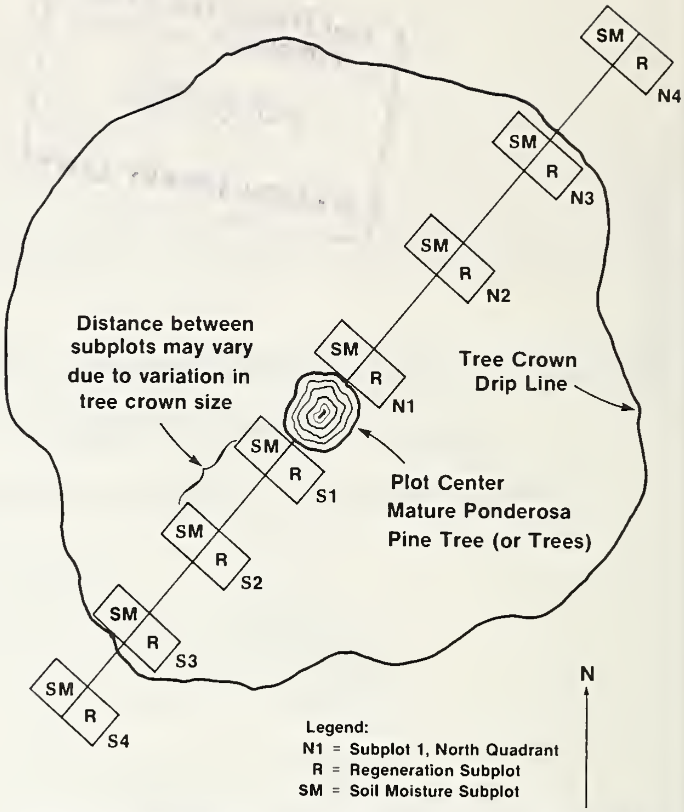

Figure 1.—Schematic of plot layout showing reference tree(s) and 1/4-milacre subplots for soil sampling and regeneration measurements.

(H) humus layer 30.1–63.5%. The fires backed evenly across the lighter fuels outside the canopy. As fire approached the heavier accumulations of litter/duff near the base of trees, the flame front slowed. The heavy accumulations around each tree ignited as glowing combustion and burned for several days.

Spikes were used to estimate the amount of duff consumed. Two rows of five spikes were uniformly spaced across each 1/2-milacre plot, with the tops of the spikes level with the top of the F layer. The exposed portion of the spikes were measured 3 weeks after the fire, after the ash and charred material had settled.

Seeds used in the study were collected from a stand similar in aspect, soil type, and elevation. Seeds were screened for soundness and viability using methods described by McLemore (1965) and Barnett and McLemore (1970). Before sowing, seeds were tagged with scandium-46, following the procedures used by Van Deusen (1971) and Lawrence and Rediske (1962), so that they could be relocated and distinguished from naturally cast seeds. A total of 1,536 seeds were sown in December 1979, 4 weeks after the burn. Sixteen seeds were placed in the south half of each 1/2-milacre plot; seeds were placed on the surface, 8 inches apart in a 4 by 4 grid. Snow covered the study area shortly afterward. To reduce the possibility of seed being eaten, rodent trapping with snap traps was begun in October 1979 and continued through November 1980.

Soil moisture was determined gravimetrically at weekly intervals from June 13 to September 30, 1980. Samples were taken from the north half of each

[2] *Personal conversation with Stephen S. Sackett, Research Forester, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz., 1980.*

[3] *Personal conversation with George Robertson, Soil Scientist, Coconino National Forest, Flagstaff, Ariz., 1984.*

1/2-milacre plot at two depths, 0-1 inch and 1-2 inches, with a 1-inch-diameter soil sampler tube, sieved through a 2-mm soil screen before being weighed, and dried at 105° F. Each depth was analyzed separately for each of the 14 sampling periods.

Supplemental water was initially applied to all plots to insure that adequate moisture was available for germination. Providing adequate moisture proved to be impossible because of the lack of natural precipitation and the logistics of the operation. Water was then applied if less than 0.5 inch of precipitation had fallen during the previous 4 days, and if the extended forecast did not predict rain anytime during the next 3 days. Under these criteria, water was applied four times. On July 18 and August 7, approximately 0.4 inch and 0.16 inch, respectively, were applied during the daytime. The last waterings, conducted after sundown to avoid wind drift and reduce evaporation, took place on August 19 and September 4 at a rate of 0.32 inch for each application.

Two continuous recording rain gauges (tipping-bucket) were used to measure precipitation. They were placed approximately 1 mile apart on the north and south boundary of the study area, to better estimate precipitation.

The location of each sown seed was determined in the fall of 1980 on burned and unburned plots. Each layer of forest floor was carefully lifted with forceps until the seed was visible. The depth of each layer (L, F, and H) was measured, as well as the depth the seed had filtered down.

Results and Discussion

Germination and Early Seedling Establishment

Germination in the Southwest generally begins in July and continues through August, coinciding with summer storms. In this study, germination occurred between the first week of August and the first week of September 1980, with late germination related to precipitation patterns. In July, 1.5 inches of rain was recorded, with 72% falling after July 20. When combined with the amount artificially applied (0.2–0.4 inch), moisture was sufficient to initiate germination. New germinants found on August 13 had received 0.6 inch of rainfall 4 days earlier, while those found August 25 received 0.9 inch of rainfall 3 days earlier. The amount of moisture applied artificially appeared insufficient to sustain germination during periods without natural precipitation.

From May to November 1980, precipitation was 5.67 inches below normal. In 1977, during this same time period, the precipitation was 2.57 inches below normal, yet seedling establishment on an adjacent burned area was very good (Sackett 1984).

Even with the poor moisture conditions, there were striking differences between the number of seedlings produced on the burned and unburned areas, and between the northeast and southwest transects. Of the 62 seedlings, 95% (59 seedlings) were found on burned plots and 5% (3 seedlings) on unburned plots. Fifty-nine seedlings were found on the northeast transects, compared to three seedlings on the southwest transects. The following tabulation shows date and rate of germination (percent of total seedlings) in relation to plot treatment:

Germination date (1980)	**Germination rate** *percent*	**Unburned plots** *number of seedlings*	**Burned plots**
Aug. 4	80	3	47
Aug. 13	8	0	5
Aug. 25	10	0	6
Sept. 8	2	0	1
Total	100	3	59

Such poor germination suggests that environmental conditions were unfavorable for seedling production, because seed viability was 98%. This is supported by observations of 33 seeds on the burned areas and 1 on the unburned area that produced radicles, yet subsequently died. They apparently were able to absorb sufficient moisture from natural rainfall and artificial waterings to initiate germination, but not enough to become established.

Birds, rodents, and drought took a heavy toll. From August 4 to August 13, 40% of the seedlings had been clipped by animals, and 34% died from lack of water. At the end of the study, only five (8%) seedlings remained alive, all on burned sites and all protected with wire cones.

Relocation of Seeds

Of the 1,536 seeds sown in December 1979, 761 (50%) were relocated as seedlings and as ungerminated seed in 1980; 333 were found on unburned plots, and 428 on burned plots.

Table 1 shows the type of seedbed on burned plots in which ungerminated seeds and seedlings were relocated. Seedlings started only when in contact with mineral soil, although various amounts of charred materials were present. Generally, the two subplots nearest the tree bole contained a heavy amount of bark, both charred and newly sluffed off. The forest floor of the outer two subplots was not always completely consumed by fire, and the seedbeds often consisted of uncharred F and H layers or only an F layer, because the H layer decreases drastically as distance from the tree bole increases, eventually disappearing beyond the canopy dripline. Frequently, the outermost subplot seedbed would consist of mineral soil and only a charred F layer in those instances where the fire was able to spread.

Mineral soil and various amounts of ash were found only when there was complete forest floor consumption, but usually charred F and H layers remained. The less compacted edges of partially consumed duff sluffed away, covering the seeds that were in contact with mineral soil. Seedlings found in this kind of seedbed were able to emerge through the material, which was generally less than 0.75-inch deep.

Table 1.—Number of southwestern ponderosa pine seeds and seedlings relocated in burned plots, by type of seedbed.

Seedbed description	Seeds found	Seedlings	Total
Mineral with light accumulation of ash	6	13	19
Heavy accumulation of ash	72	6	78
Charred H with ash and mineral soil exposed	113	14	127
Charred F with mineral soil exposed	26	26	52
Uncharred F and H layers	131	0	131
Uncharred F layer without developed H layer	9	0	9
Other—on top of wood, grass, or bark	12	0	12
Total	369	59	428

Seeds on unburned plots generally were more visible than those on burned plots. No seeds penetrated deeper than 0.75 inch into the H layer, which ranged from 0 to 6.3 inches in depth. Of the 330 seeds recovered on the unburned plots, only 6 (2%) had filtered down to the mineral soil. The remainder were distributed as follows: none in the L layer; 162 (49)% in the F layer; 121 (37%) on top of the H layer; 31 (9%) under cone or woody material; and 10 (3%) on top of rock, grass, or woody material. A continuous mat, consisting of needles and fungal hyphae, forms at the interface between the F and H layers, apparently keeping seed elevated above the humus layer and mineral soil. Seeds can only reach lower depths if the layer is broken by falling branches, trampling by large animals, or other disturbances. Only three seedlings were found on unburned plots, and all were on mineral soil covered by a light accumulation ($\leqq$0.5 inch) of newly fallen litter. Such seedbeds are usually found only at the edge or beyond the tree canopy.

Soil Moisture

In those instances where significant soil moisture differences were found between treatments, the soil moisture was always higher on burned than unburned plots at both 0-1 inch and 1-2 inch depths (table 2). There were fewer periods where significant differences were noted in the 0-1 inch layer (four sample periods) than in the 1-2 inch layer (nine sample periods). Sample periods that exhibited significant differences for the upper layer correspond with periods of heavy and no natural precipitation. There appeared to be no relationship between periods with significant soil moisture differences and the timing of artificial application of moisture. The first sample period in which significant moisture differences corresponded with seed germination occurred July 24 for the 1-2 inch depth. During the following week there was almost daily precipitation, which apparently equalized soil moisture between the two treatments, since there was no significant difference July 30. A significant difference developed and persisted from July 30 to the end of sampling, even though precipitation was intermittent and moisture conditions could have been considered critical.

On a basaltic soil adjacent to this study, Ryan (1978) also found higher soil moisture conditions on prescribed burned sites compared to unburned sites. This difference is related to the lack of litter and humus to intercept moisture during the single storms. It appears that moisture is able to reach mineral soil if there is daily moisture present. When 1 or 2 days of rain are followed by several dry days, the moisture may be retained in the litter layer and may not reach mineral soil.

The 0-1 inch layer of mineral soil most often showed significant differences when the two azimuths were compared (table 2). For nine sample periods, eight of which occurred July 25 and later, the northeast half of the transect had significantly higher soil moisture compared to the southwest aspect. The higher soil moisture on the northeast transect is also reflected in the greater number of seeds germinating on this portion of the transect. Soil moisture at 1-2 inches depth was significantly higher on the northeast side on July 30, following a 5-day rainy period, and when soils were measured August 14 after a 5-day dry period. Differences also were found August 22, after a 13-day dry period that was interrupted with the application of 0.32 inch of water 3 days prior to sampling, and on September 25, after a 15-day dry period. There again appears to be no set pattern when significant differences would appear in relation to azimuth, since they occurred at times of high moisture and when there was no precipitation.

There were significant differences in soil moisture at both soil depths between subplots located near the bole of the tree and those extending beyond the canopy (table 3). Subplots nearest the bole had higher moisture contents before any precipitation or water application. Once rainfall began, subplots outside the canopy maintained higher soil moisture contents. During periods with little or no precipitation, outer subplots dried faster at the 0-1 inch depth and were lower in moisture content than subplots under the canopy. Such changes in moisture content patterns are most likely related to canopy interception and water flow down the trunk.

A review of results suggests that watering may have increased soil moisture content; but, the overall effect of the canopy on shading, drying, and precipitation interception is still evident (table 3).

Fuel Reduction

The amount of litter and duff removed and the area of mineral soil exposed by prescribed burning was greatest around the base of the trees. Completeness of

Table 2.—Mean soil moisture content (percent) of southwestern ponderosa pine subplots.[1]

Sampling date (1980)	0-1 inch soil depth				1-2 inch soil depth			
	Burned	Unburned	NE	SW	Burned	Unburned	NE	SW
June 13	12.79	11.25	11.91	12.12	15.21	13.09	14.61	13.70
June 26	11.24	10.53	12.02*	9.75	13.67	11.54	12.95	12.25
July 3	18.35	19.84	18.45	19.73	16.22	16.10	15.25	17.07
July 10	12.85	12.81	13.07	12.59	13.97*	12.54	13.03	13.49
July 17	8.97	9.56	9.89	8.65	11.60	10.64	11.28	10.96
July 24	20.89*	15.54	19.20*	17.24	17.18*	13.01	14.90	15.29
July 31	25.71	21.41	25.49*	21.63	21.02	17.21	20.36*	17.87
Aug. 7	14.80	13.81	15.26*	13.35	14.88*	12.73	14.37	13.24
Aug. 14	18.09	16.29	19.68*	14.70	16.95*	13.82	16.89*	13.88
Aug. 22	17.19	14.14	18.65*	12.69	15.97*	12.71	15.94*	12.74
Aug. 29	19.38	17.22	19.57*	17.03	17.80*	14.82	16.71	15.91
Sept. 4	13.63*	12.13	13.71*	12.05	15.13*	11.81	13.61	13.32
Sept. 12	19.04*	13.63	16.86	15.82	16.04*	12.08	14.62	13.51
Sept. 25	12.93*	10.31	12.85*	10.39	14.06*	10.65	12.94*	11.77

[1]Treatments are combined to determine means of direction from tree.
Asterisk (*) denotes that a treatment or direction mean is significantly different (P = 0.05).

Table 3—Mean soil moisture content (percent) of southwestern ponderosa pine seedbeds by subplot spacings.[1]
(Subplot closest to tree is 1; subplot outside canopy is 4.)

Sample period	0-1 inch soil depth of subplot—				1-2 inch soil depth of subplot—			
	1	2	3	4	1	2	3	4
June 13	20.20 a[1]	12.40 a	10.61 ab	4.87 b	17.48 a	14.07 b	13.21 bc	11.86 c
June 26	15.01 a	11.35 ab	9.85 b	7.33 c	14.79 a	13.70 ab	12.10 b	9.83 c
July 3	19.81	17.57	18.02	20.98	16.60	15.26	15.33	17.45
July 10	14.78 a	11.87 ab	13.67 ab	11.00 b	13.82	12.71	13.77	12.73
July 17	12.57 a	9.17 b	8.50 bc	6.83 c	12.53 a	11.26 b	10.85 bc	9.85 c
July 24	16.69 a	16.37 a	18.58 ab	21.23 b	14.98	14.30	15.11	15.99
July 31	20.72 ab	20.16 a	24.55 b	28.81 c	17.20 a	16.83 a	19.35 a	23.08 b
Aug. 7	13.75	13.09	15.61	14.77	12.86	13.28	14.07	15.00
Aug. 14	17.63	16.71	17.39	17.03	15.66	15.47	14.97	15.44
Aug. 22	18.43 a	14.67 b	14.48 b	15.09 ab	16.26 a	13.47 b	13.82 ab	13.81 ab
Aug. 29	17.69	17.70	18.96	18.85	15.31	16.07	16.73	17.14
Sept. 4	13.57	12.63	13.07	12.25	14.21	13.77	13.35	12.54
Sept. 12	17.51	14.89	15.69	17.25	14.55	13.13	13.65	14.93
Sept. 25	13.35 a	11.19 ab	11.83 ab	10.11 b	13.14	12.27	12.33	11.67

[1]Sample period means with like letters are not significantly different (P = 0.05) for each depth. Sample periods without letters have no significant differences between plots. Tested using Tukey's W procedure.

forest floor removal decreased with distance from the base of the trees. Subplots 1 and 2 were significantly different (p = 0.05) from each other and from subplots 3 and 4 in amount of forest floor consumed. Generally, the F and H layers remained intact in the outer subplots, except where a large piece of wood ignited, consuming the adjacent forest floor. Analysis of variance revealed no significant difference, at the 0.05 level, in the amount of duff consumed or in the percentage of mineral soil exposed between the northeast and southwest subplots.

Literature Cited

Barnett, J. L., and B. F. McLemore. 1970. Storing southern pine seeds. Journal of Forestry 68:24–27.

Biswell, Harold H. 1972. Fire ecology in ponderosa pine-grassland. Tall Timbers Fire Ecology Conference 12:69–96.

Cooper, Charles F. 1961. The ecology of fire. Scientific American 204:217–223.

Dieterich, John H. 1980. Chimney Springs forest fire history. USDA Forest Service Research Paper RM-220, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Fahnestock, George R. 1973. Use of fire in managing forest vegetation. Transactions of the American Society of Agricultural Engineers 16:410–413, 419.

Heidmann, L. J. 1976. Frost heaving of tree seedlings: A literature review of causes and possible control. USDA Forest Service General Technical Report RM-21, 10 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heidmann, L. J., Frederic R. Larson, and W. J. Rietveld. 1977. Evaluation of ponderosa pine reforestation techniques in central Arizona. USDA Forest Service Research Paper RM-190, 10 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Kallender, Harry R., Harold Weaver, and Edward M. Gaines. 1955. Additional information on prescribed burning in virgin ponderosa pine in Arizona. Journal of Forestry 53:730–731.

Lawrence, William H., and J. H. Rediske. 1962. Fate of sown Douglas-fir seed. Forest Science 8:210–218.

McLemore, B. F. 1965. Pentane flotation for separating full and empty longleaf pine seeds. Forest Science 11:242–243.

Mutch, Robert W., and James R. Habeck. 1975. Forest and forestry. p. 209–212. *In* McGraw-Hill Yearbook of Science and Technology. McGraw-Hill Book Co., New York, N.Y.

Pearson, G. A. 1950. Management of ponderosa pine in the Southwest. Agriculture Monograph 6, 218 p. U.S. Department of Agriculture, Washington, D.C.

Ryan, Michael G. 1978. The effect of prescribed burning in ponderosa pine on the inorganic nitrogen content of the soil. M.S. thesis, 64 p. Northern Arizona University, Flagstaff.

Sackett, Stephen S. 1979. Natural fuel loading in ponderosa pine and mixed conifer forests of the Southwest. USDA Forest Service Research Paper RM-213, 10 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Sackett, Stephen S. 1984. Observations on natural regeneration in ponderosa pine following a prescribed fire in Arizona. USDA Forest Service Research Note RM-435, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Schubert, Gilbert H. 1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA Forest Service Research Paper RM-123, 71 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Van Deusen, James L. 1971. Radio-tagged seeds easily relocated in Black Hills trails. Proceedings of the South Dakota Academy of Science 50:238–242.

Weaver, Harold. 1951. Fire as an ecological factor in the southwestern ponderosa pine forests. Journal of Forestry 49:93–98.

Weaver, Harold. 1956. Wild fires threaten ponderosa pine forests. American Forests 62:28–29, 52–55.